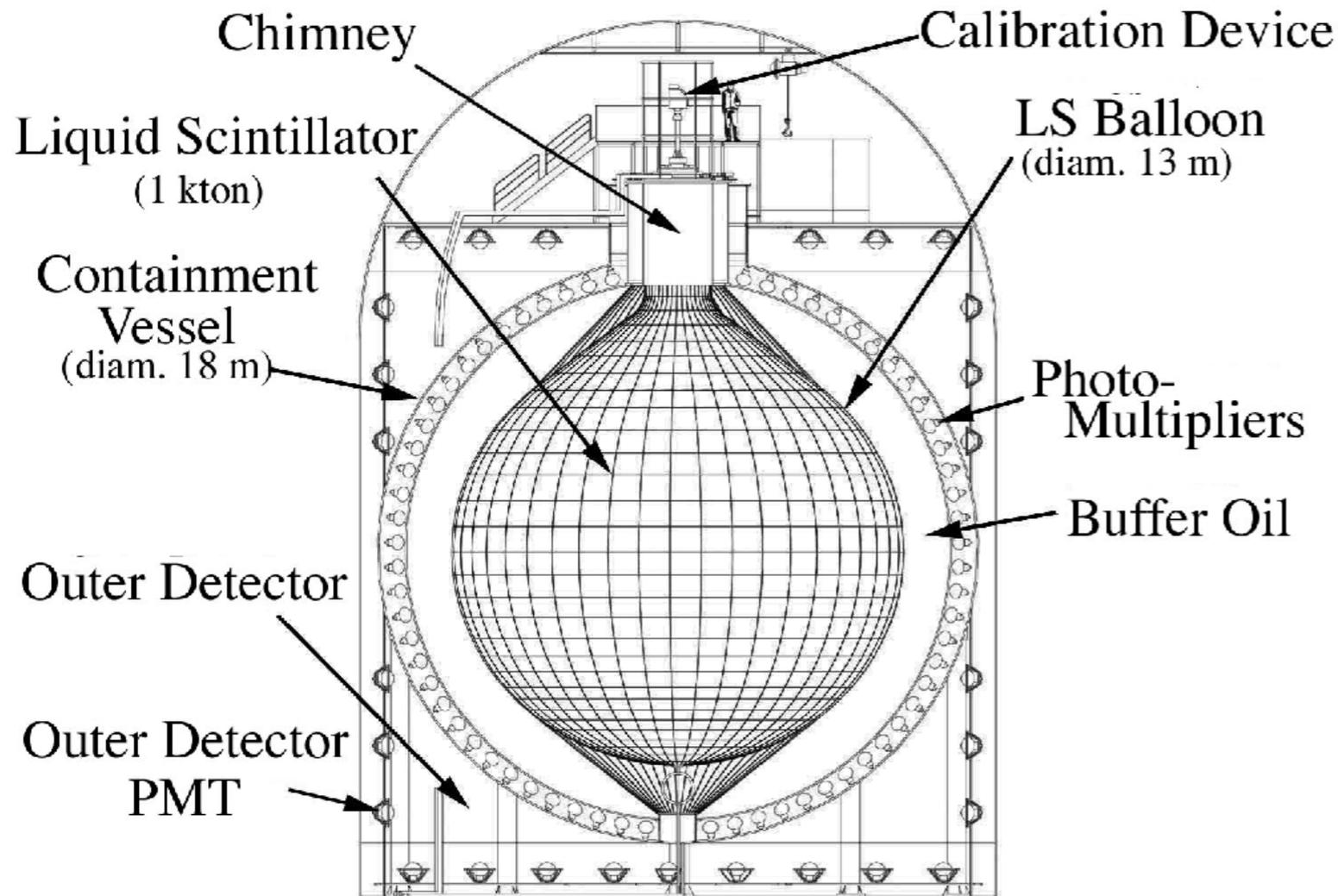


# KamLAND-Zen and R&D for large LS detectors

Brian Fujikawa (LBNL) & Lindley Winslow (MIT)

# KamLAND Detector

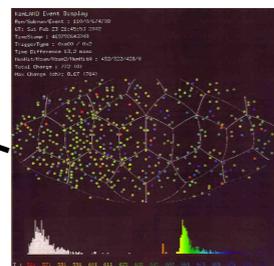
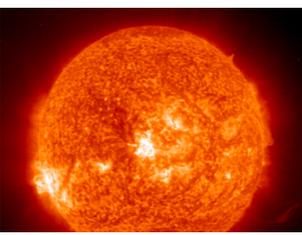
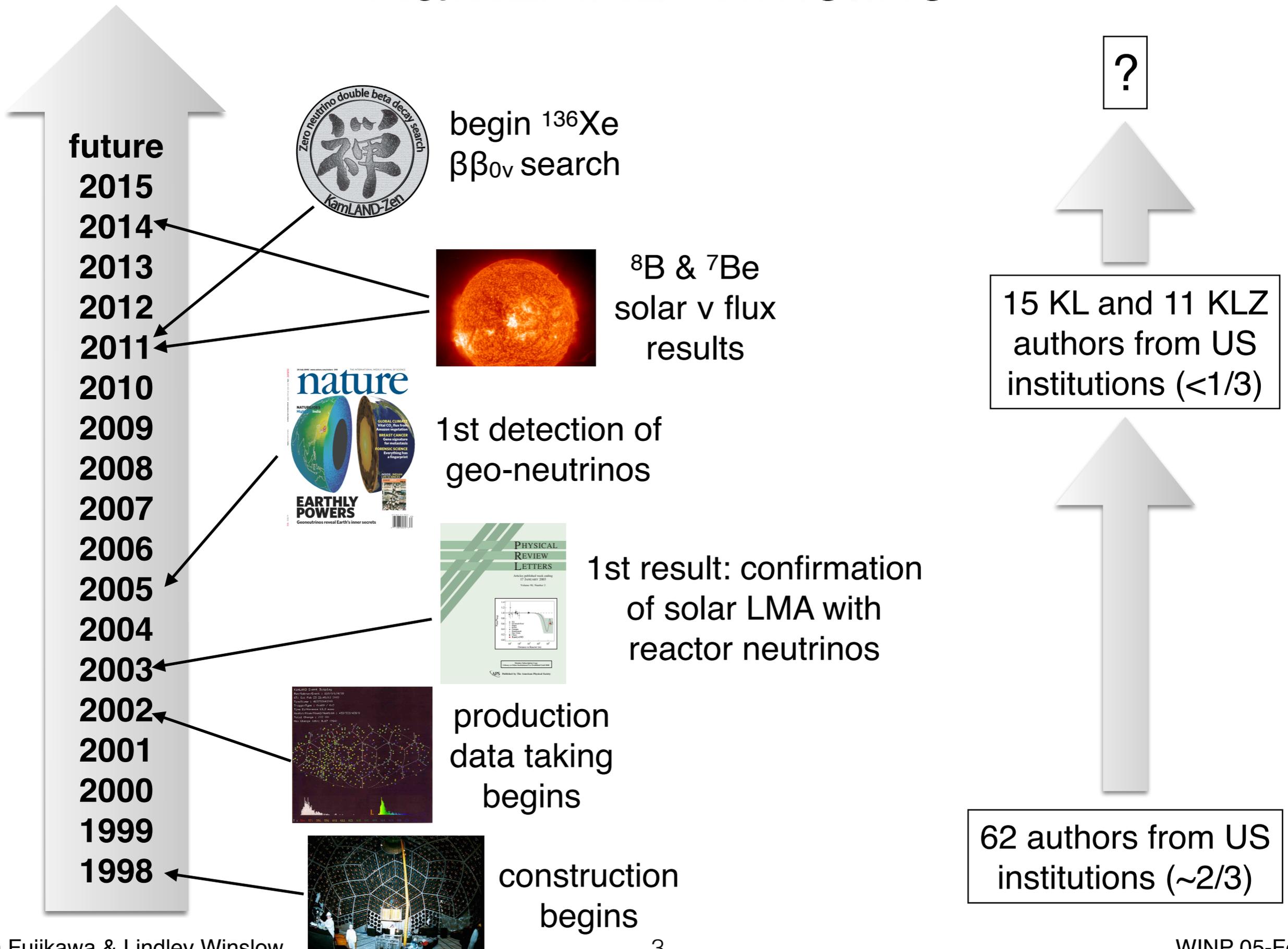


- LS:  $\text{CH}_{1.9}\text{n}$
- 1879 PMTs
  - 1325 17-inch
  - 554 20-inch
  - 34% coverage

$$\frac{\sigma_E}{E} = \frac{6.5\%}{\sqrt{E[\text{MeV}]}}$$

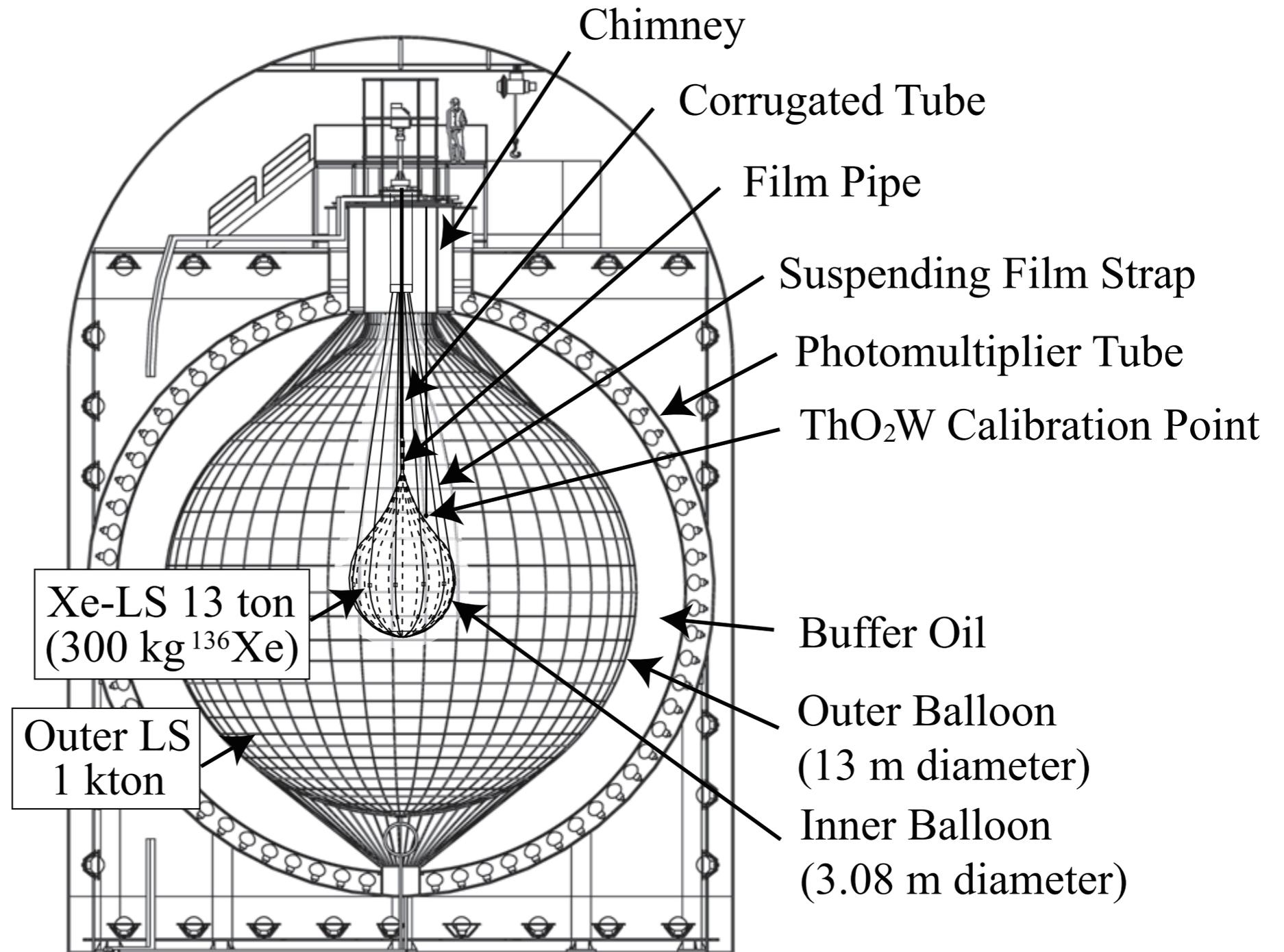
$$\sigma_{\vec{R}} = \frac{12 \text{ cm}}{\sqrt{E[\text{MeV}]}}$$

# KamLAND Timeline

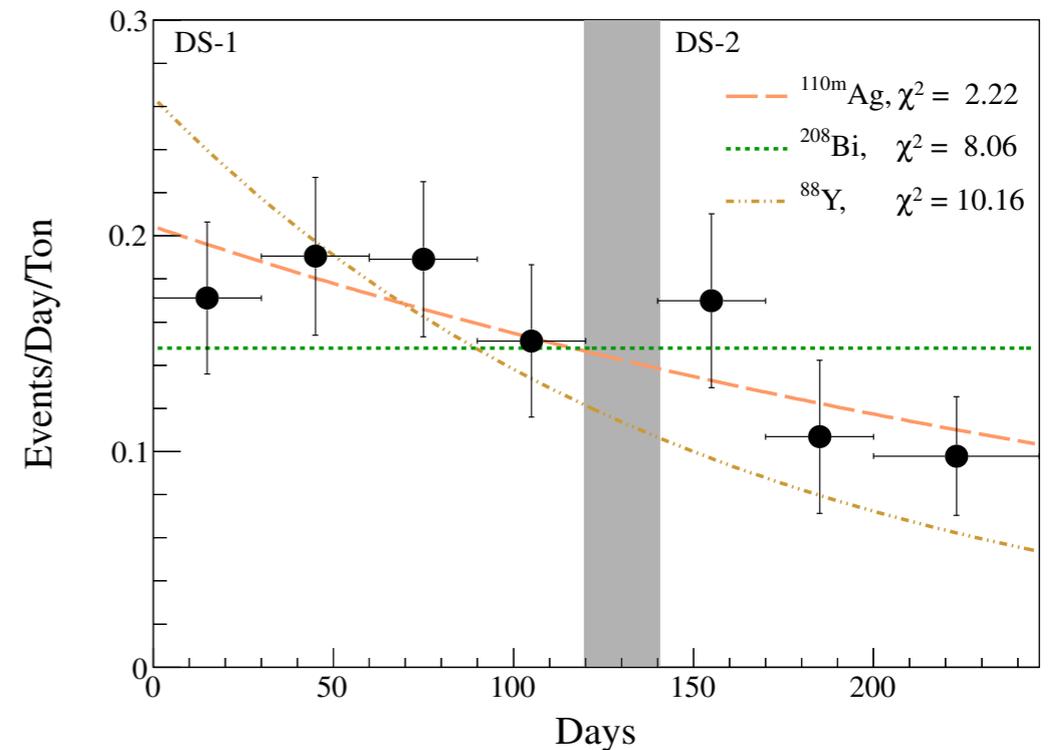
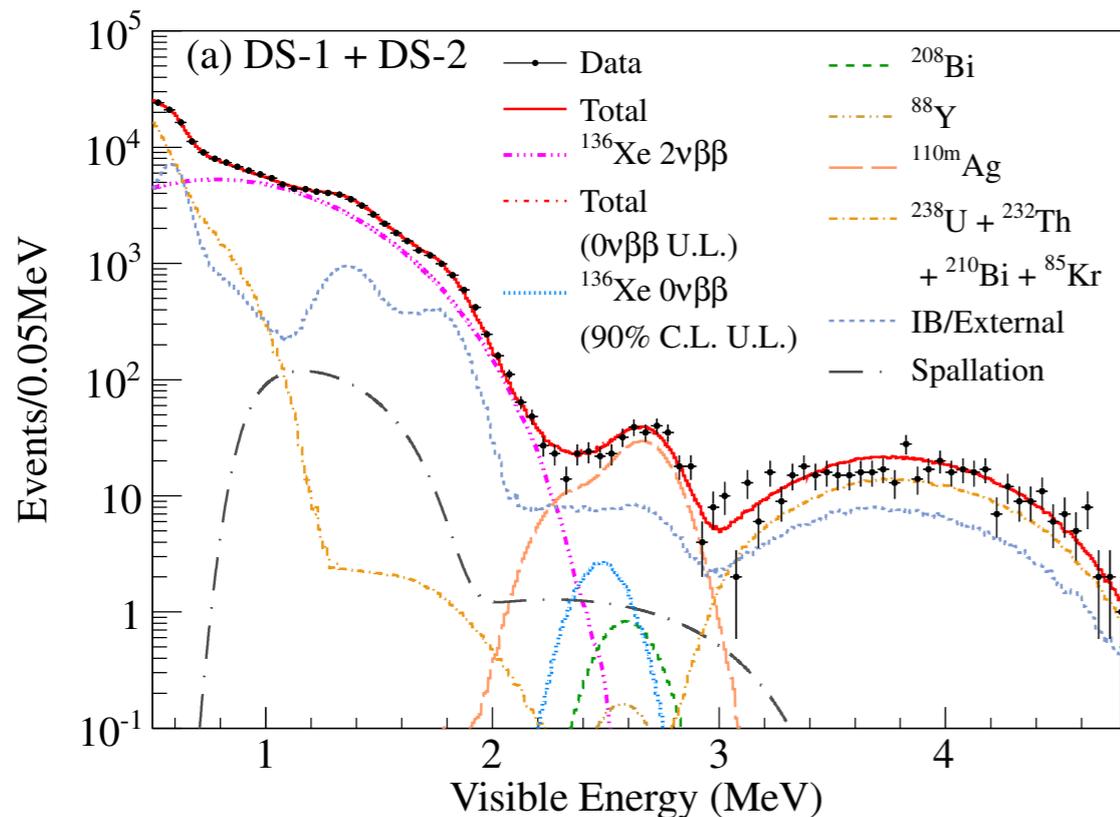


# KamLAND-Zen

enrichment:  
 $\sim 90\% \text{ }^{136}\text{Xe}$



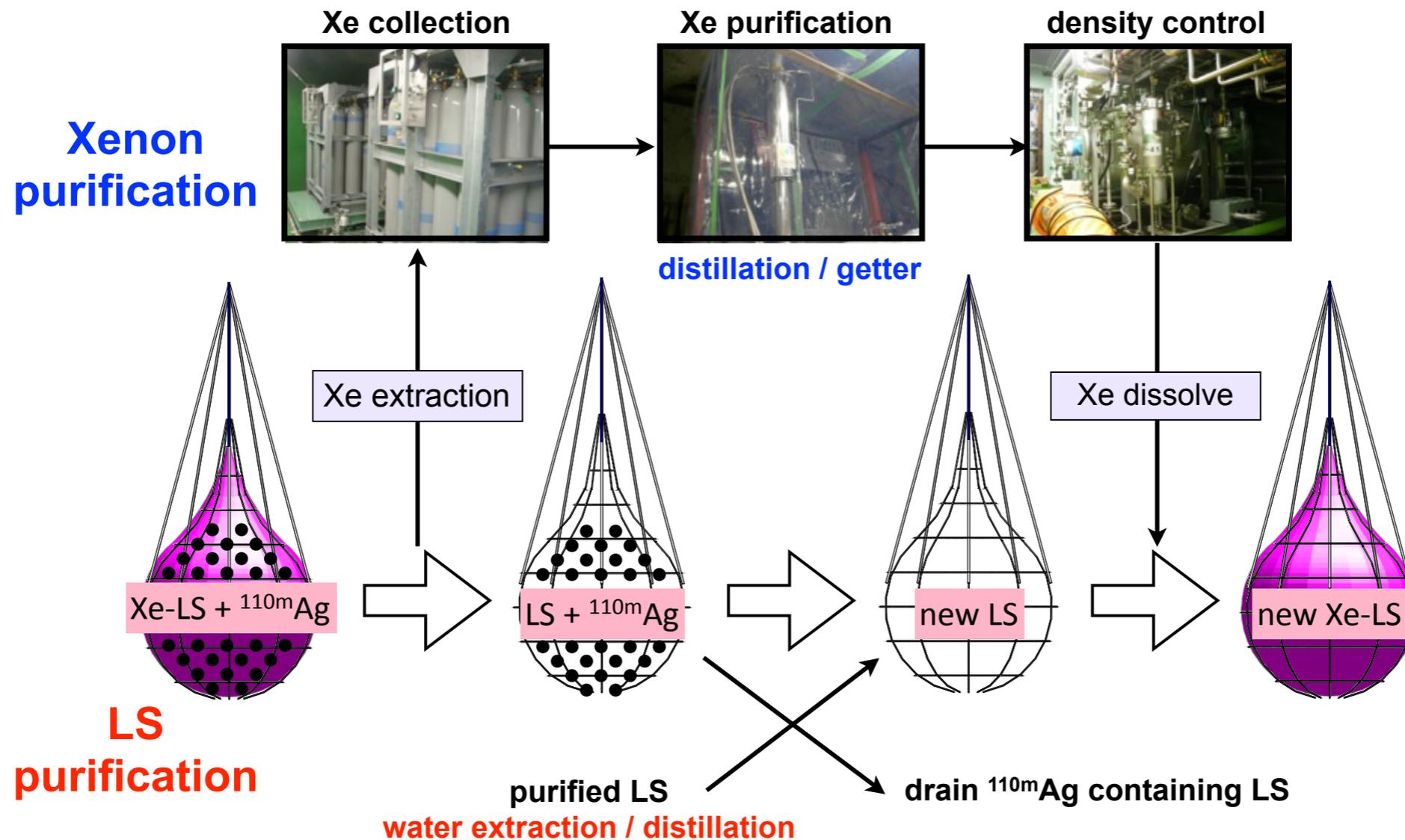
# KamLAND-Zen Phase 1



- 89.5 kg · yr exposure
- Significant background in ROI:
  - spectral fits and lifetime favors  $^{110\text{m}}\text{Ag}$
  - possibly from Fukushima fallout
- $T_{1/2}(0\nu) > 1.9 \times 10^{25}$  yr (90% C.L.)
- Phys. Rev. Lett. **110**, 062502 (2013)

# In-situ KamLAND-Zen “Upgrade”

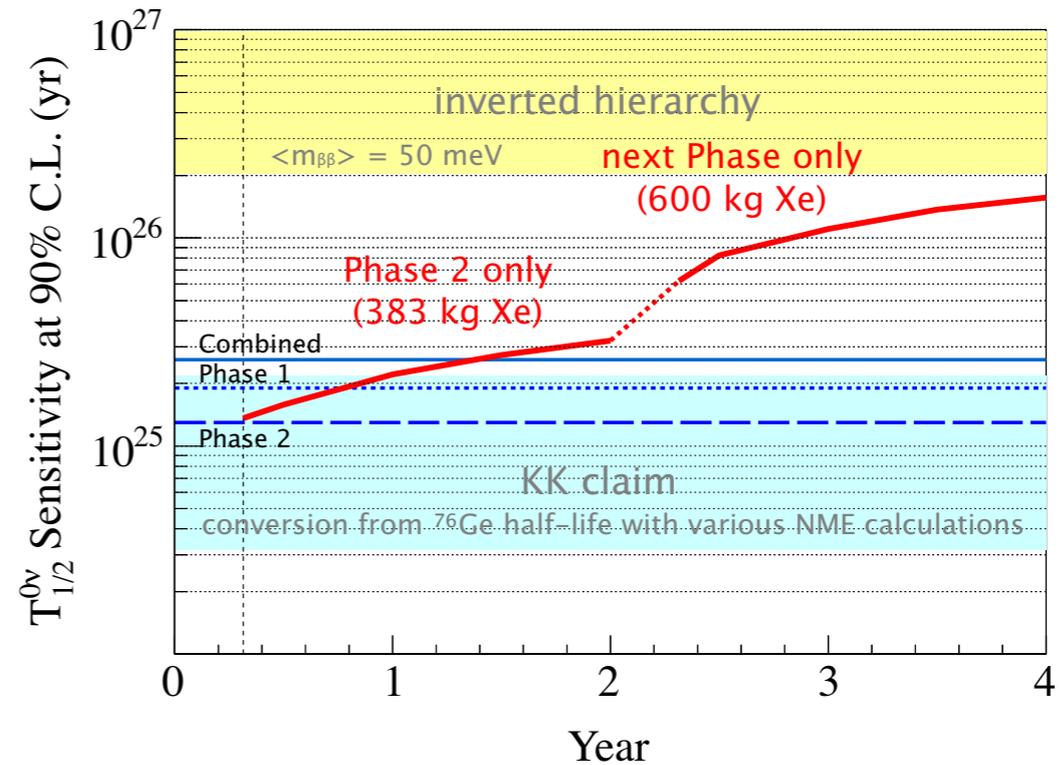
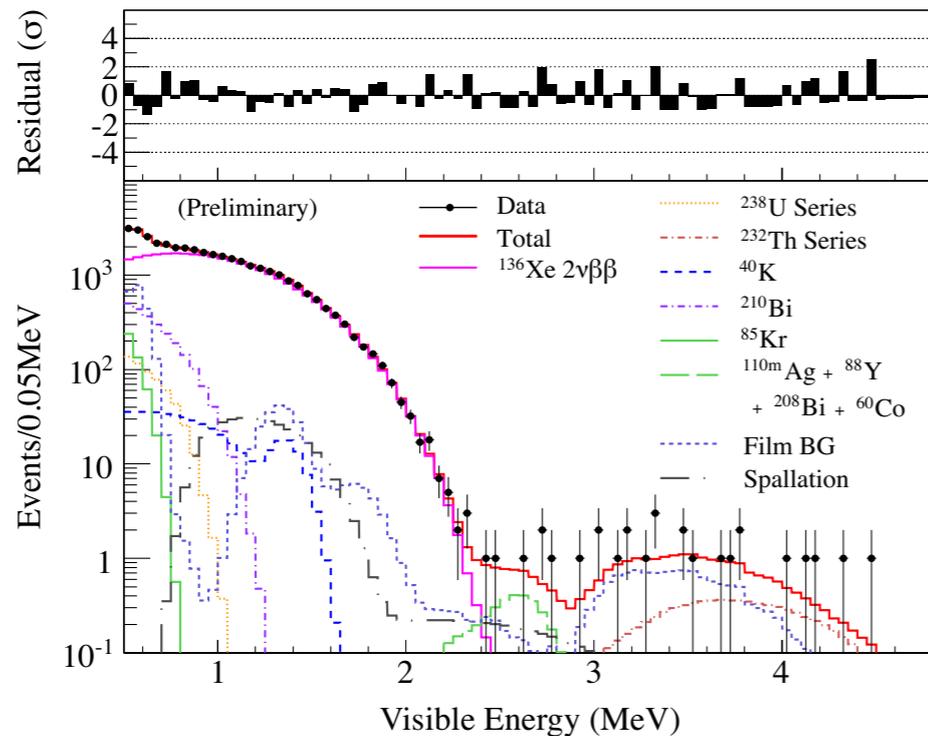
## Purification Strategy



Xenon and LS purification to reduce radioactive impurities

from Itaru Shimizu (Neutrino 2014)

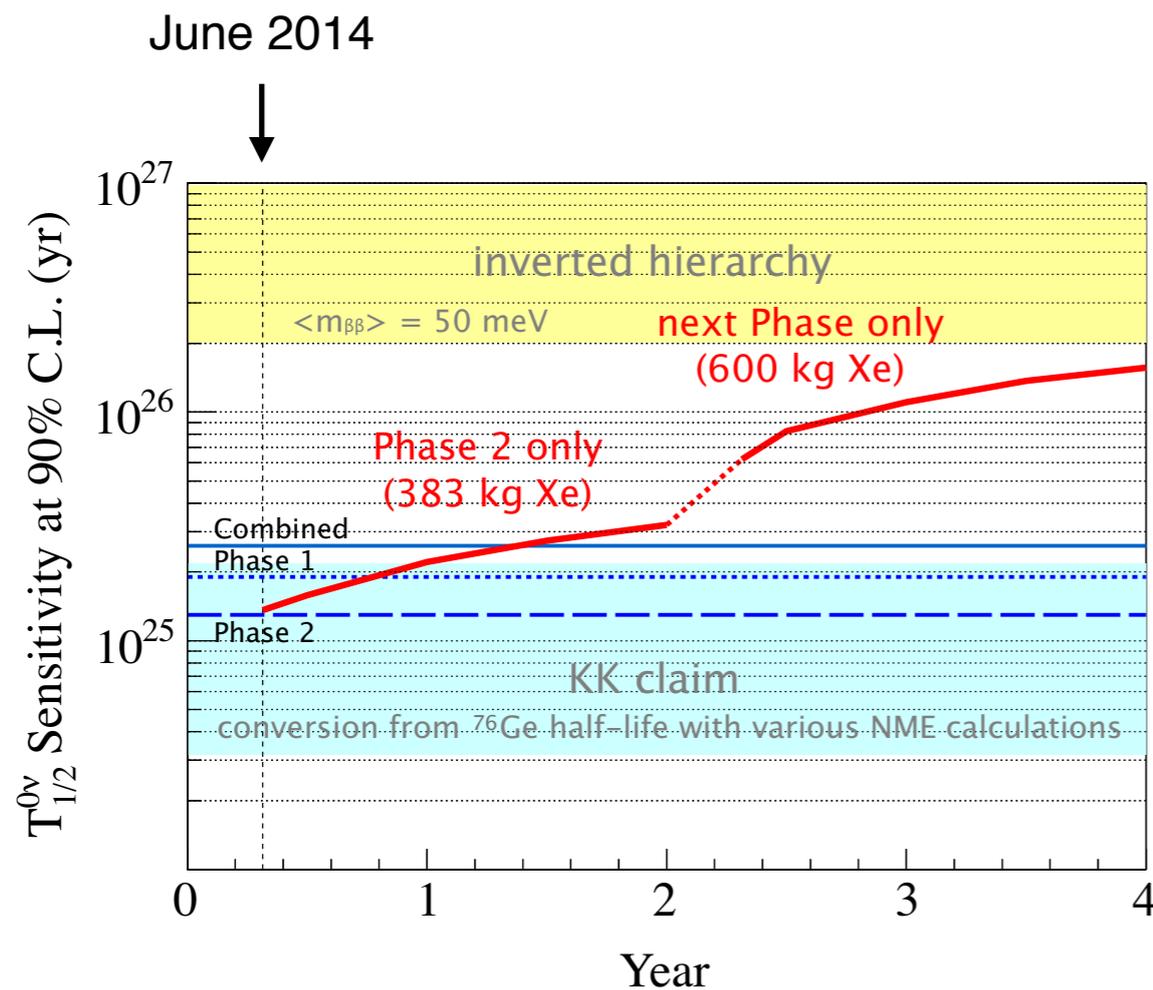
# KamLAND-Zen Phase 2



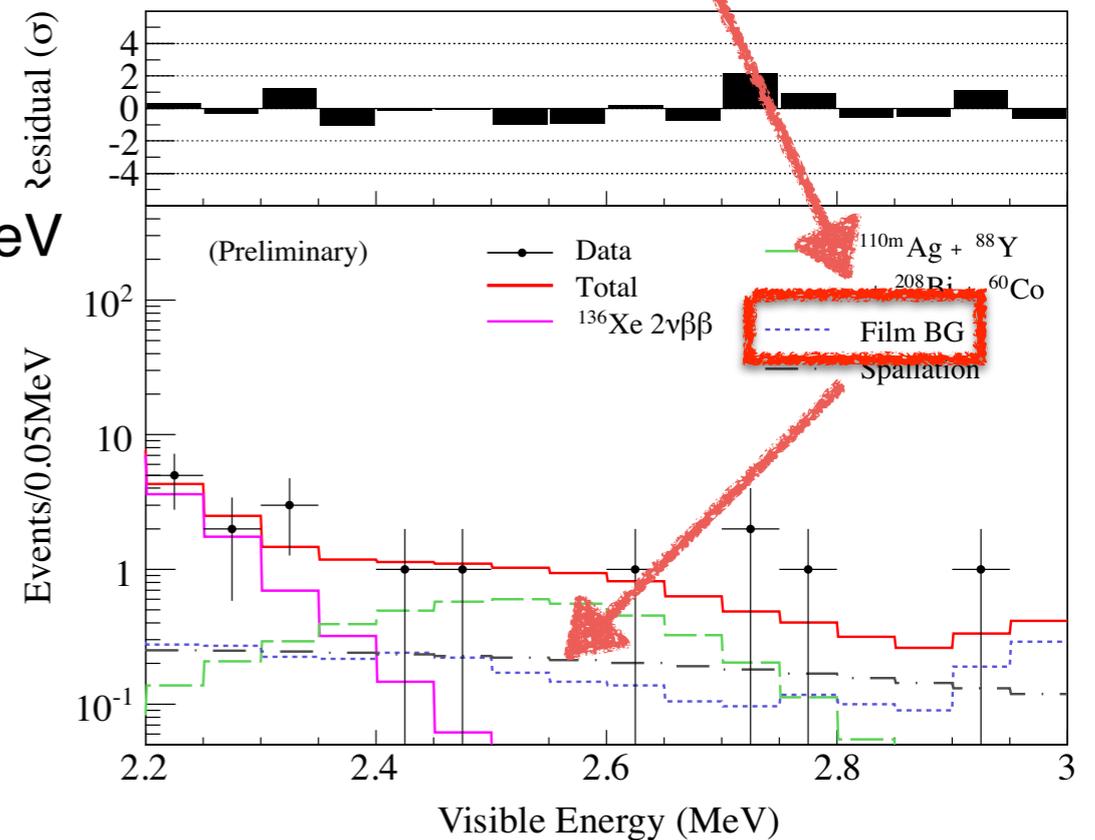
- $> \times 10$  reduction in ROI background
- Preliminary Neutrino 2014 results:
  - $T_{1/2}(0\nu) > 1.3 \times 10^{25} \text{ yr}$  (90% C.L.) Phase II only
  - $T_{1/2}(0\nu) > 2.6 \times 10^{25} \text{ yr}$  (90% C.L.) Phase I & II
- Data taking continues through ~fall 2015

# KamLAND-Zen Next Phase

- Cleaner balloon: improved control of contamination by fallout and other sources
- Larger balloon: 383 kg  $\rightarrow$  600 kg Xe
- Additional upgrades depending on success of current R&D effort:
  1. High pressure Xe loading R&D:  $\rightarrow$  800 kg Xe
  2. Scintillating balloon: reduce background from the balloon film



$\sim 50$  meV



# KamLAND2-Zen (Major Upgrade)

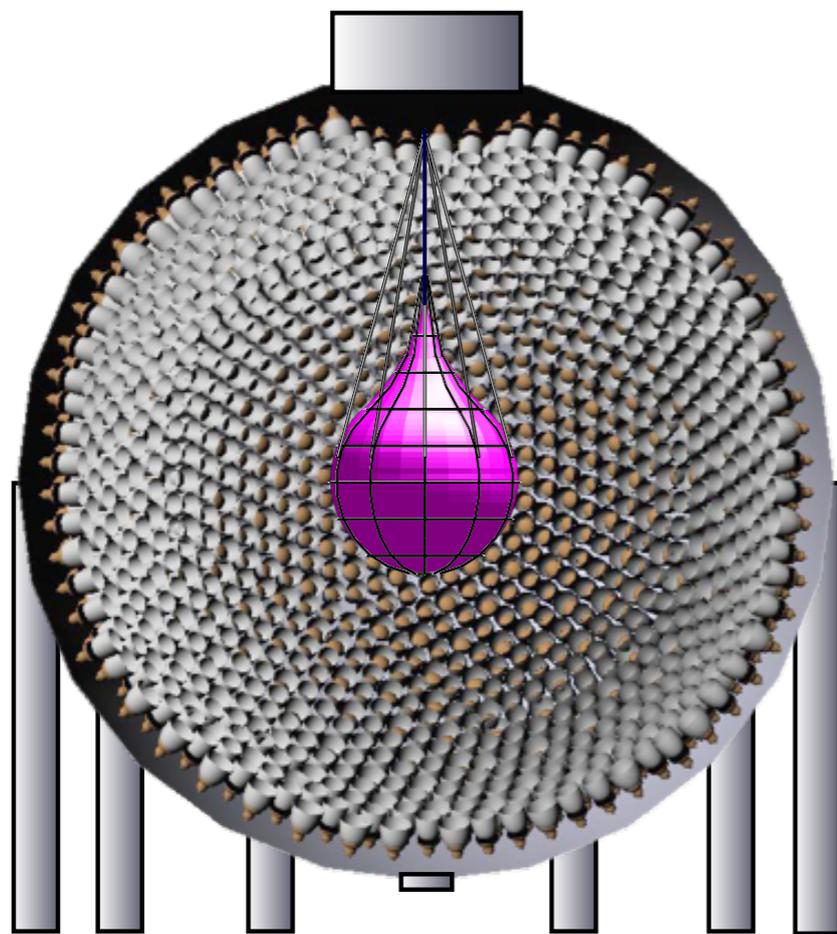
## KamLAND2-Zen

### General-purpose

larger crane  
strengthen floor  
**enlarge opening**

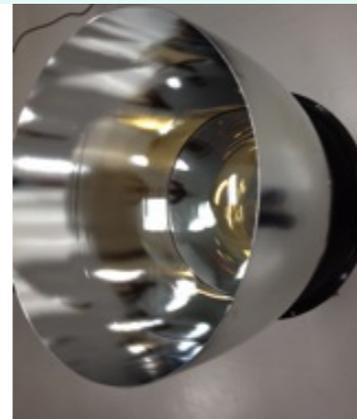
accommodate various devices  
CaF<sub>2</sub>, CdWO<sub>4</sub>, NaI, ...

**1000 kg enriched Xe**

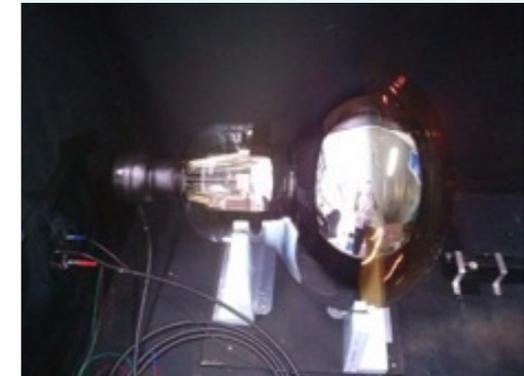


### High performance

#### Winstone Cone



#### High Q.E. PMT



17"Φ → 20"Φ, ε=22% → 30%

Photo-coverage > **x2**

Light Collection Eff. > **x1.8**

**x1.9**

#### New Liquid Scintillator

**x1.4**

KamLAND liquid scintillator 8,000 photon/MeV  
typical liquid scintillator 12,000 photon/MeV

$\sigma(2.6\text{MeV}) = 4\% \rightarrow < 2.5\%$

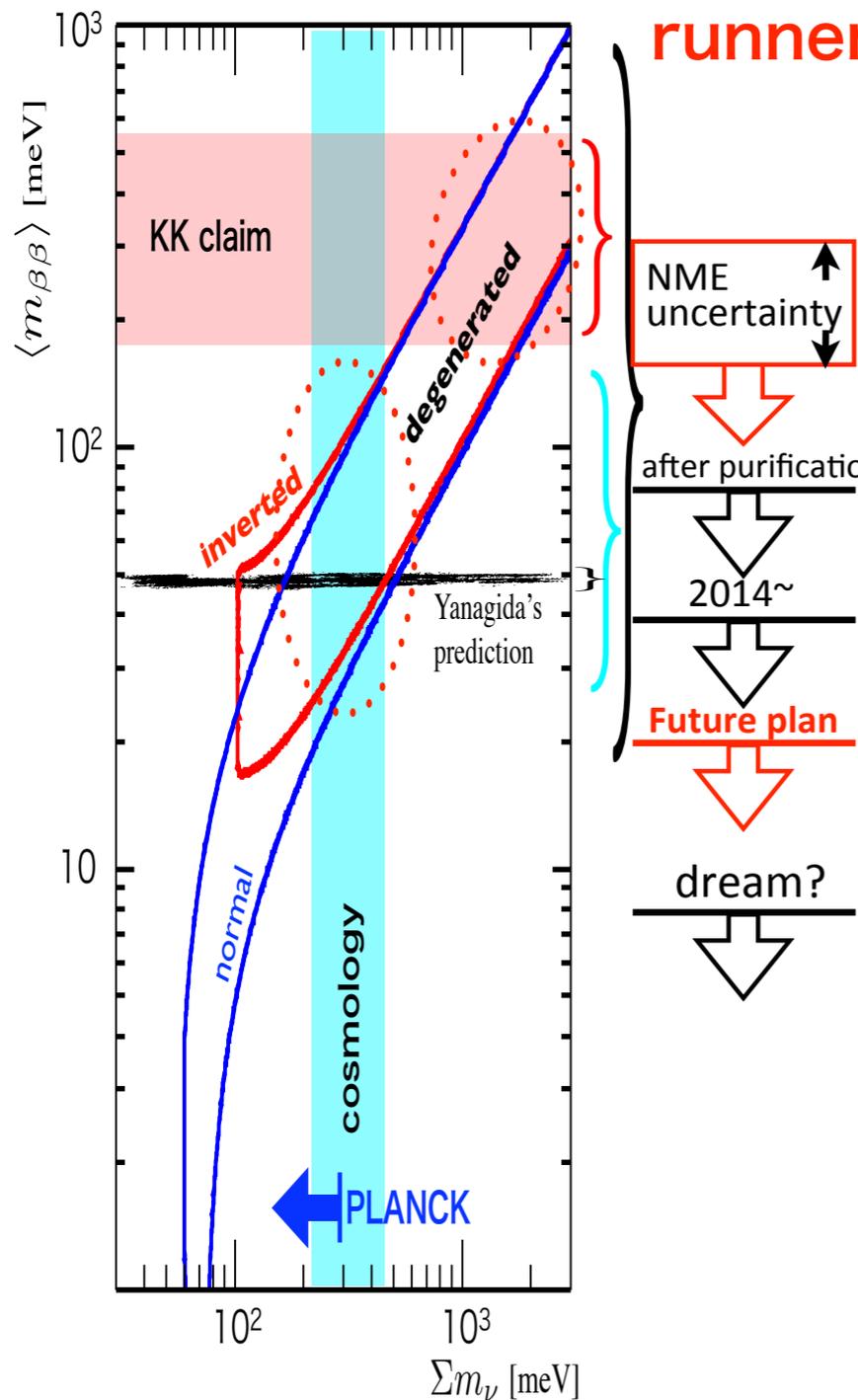
naive calc. < 2%

target  $\langle m_{\beta\beta} \rangle \sim$  **20 meV / 5 year**

from Itaru Shimizu (Sept 2014)

# KamLAND-Zen Prospects

## Prospects



from Kunio Inoue (ISOUPS 2013)

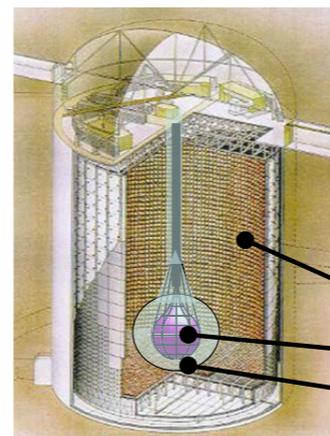
**KamLAND-Zen is a top runner and being improved.**

KamLAND-Zen 89.5 kg-yr  
 $\langle m_{\beta\beta} \rangle < 160 \sim 330 \text{ meV}$  @90% C.L.  
 the world best

KamLAND-Zen 2nd phase (2013 fall -)  
 100 times  $^{110m}\text{Ag}$  reduction expected

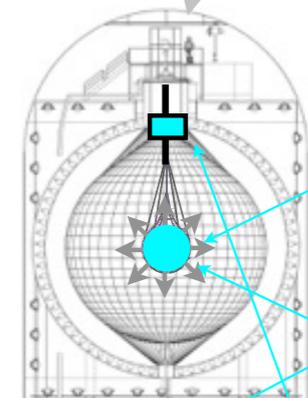
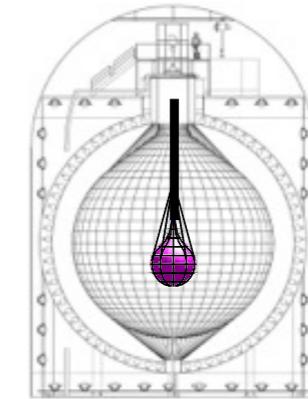
KamLAND-Zen 600kg  
 with clean mini-balloon

**KamLAND2-Zen : high QE PMT, high yield LS, light concentrator**  
 $\sigma_E(2.6\text{MeV}) = 4\% \rightarrow < 2.5\%$   
 Super-KamLAND-Zen



water or LS  
 Xenon-LS  
 normal LS

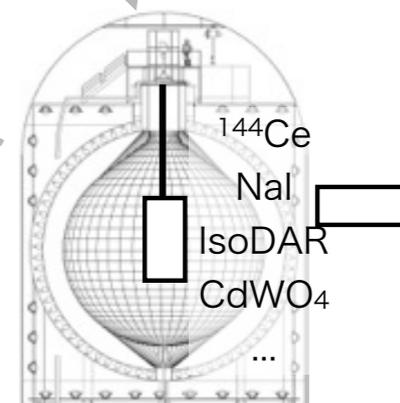
precision anti-neutrino physics  
 $p \rightarrow \nu K^+$  is also possible.



R&D for pressurized Xe

R&D for scintillation film

R&D for  $\beta / \gamma$  discrimination (high sensitivity imaging)

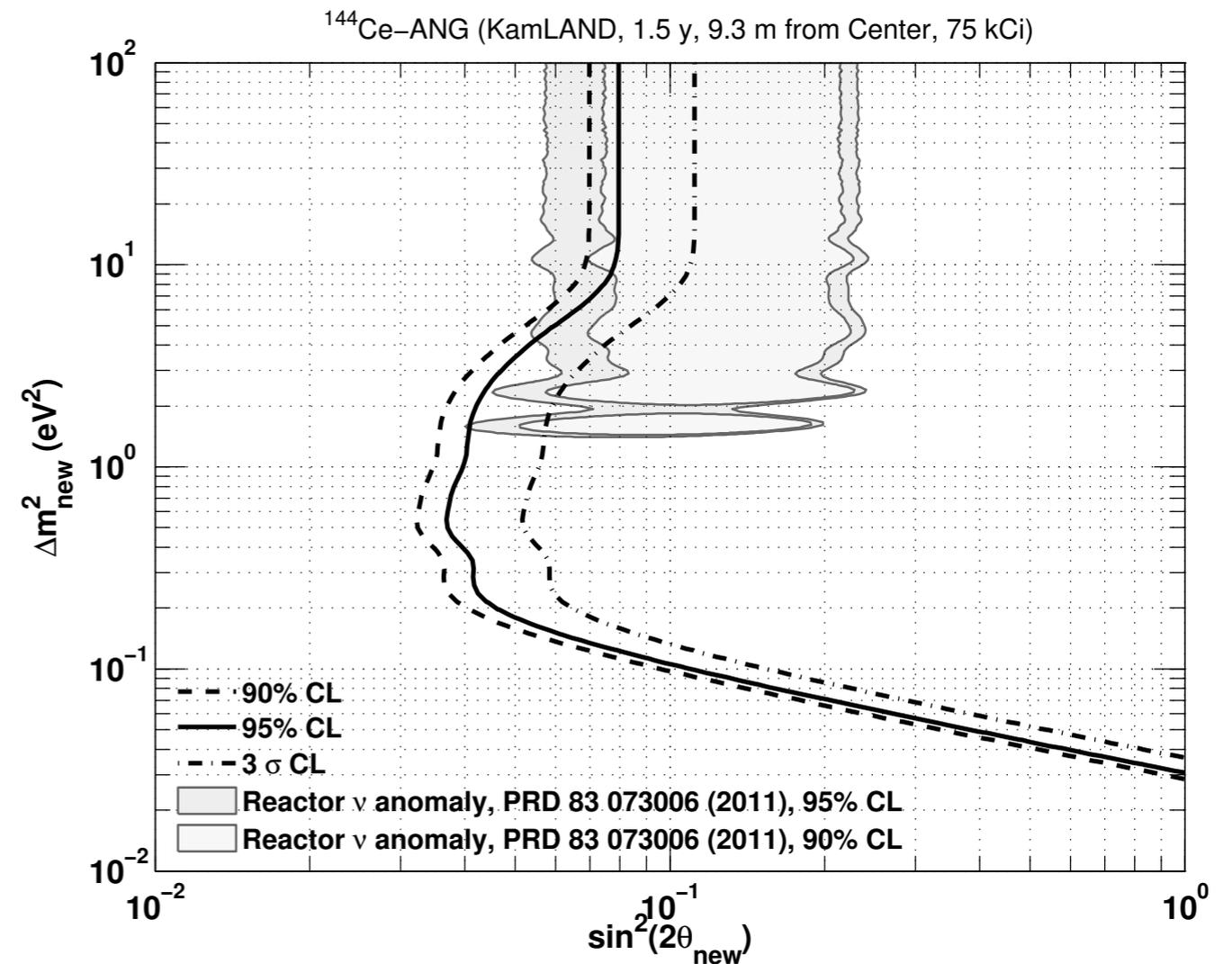


$^{144}\text{Ce}$   
 $\text{NaI}$   
 IsoDAR  
 $\text{CdWO}_4$   
 ...  
 Various low BG measurement can be accommodated.

# Testing the Reactor $\nu$ Anomaly with KamLAND

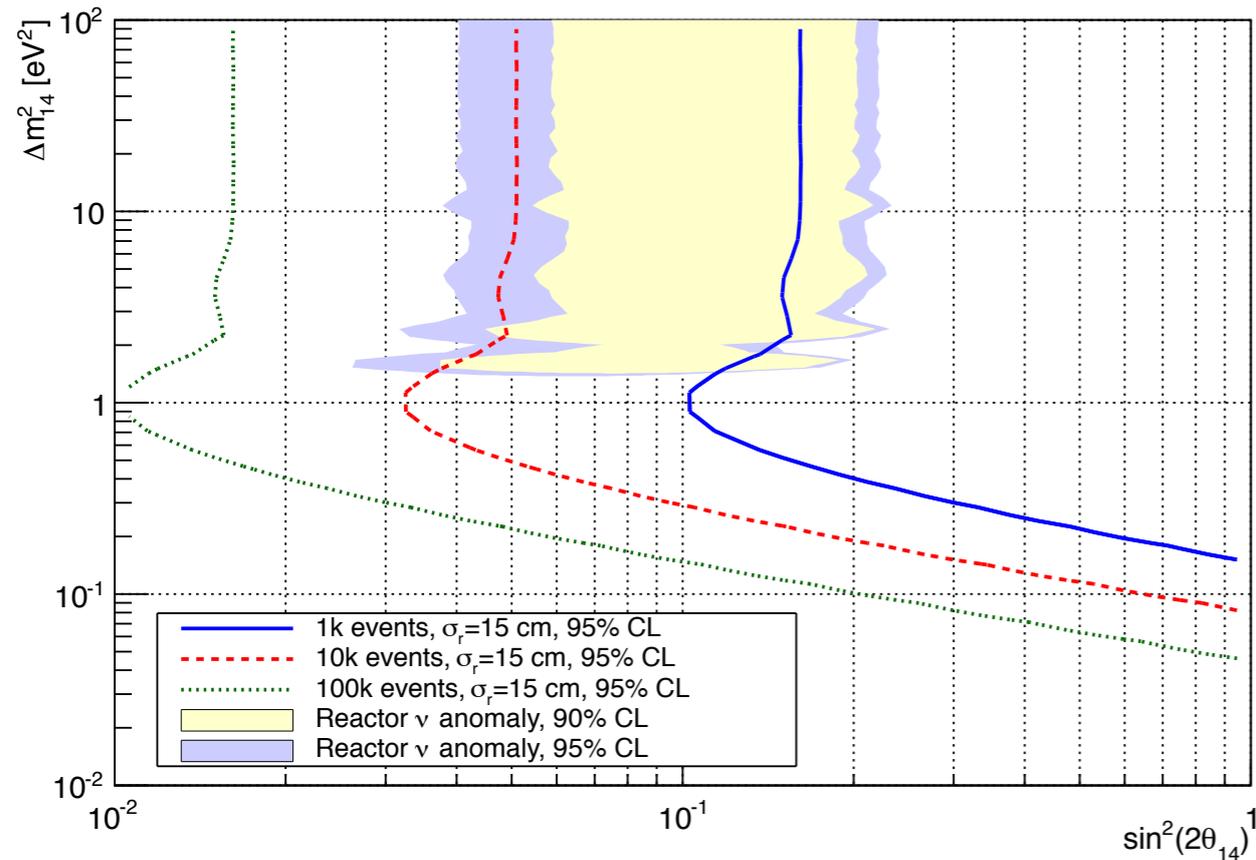
CeLAND (*now deceased*)

- 75 kCi  $^{144}\text{Ce}$  source
- 9.3 m from KL center
- arXiv:1312.0896
- Please see session on: ***Technology: Source, cyclotron & meson decay at rest***



# DAR $^8\text{Li}$ Sources and KamLAND

calculation by Dan Dwyer



- IsoDAR
  - $\mathcal{O}(10^{13} \text{ } ^8\text{Li}/\text{sec})$  source possibilities:
    1.  $^7\text{Li}(d,p)^8\text{Li}$  (10 mA, 2 MeV  $^2\text{H}$  beam)
    2.  $>10^{14}$  n/sec D-T generator
  - Other physics:
    - e.g. Phys. Rev D **89**, 072010 (2014)
- Please see session on: ***Technology: Source, cyclotron & meson decay at rest***

$^8\text{Li}$  Rate

IBD (5 Years)

$10^{11} \text{ } ^8\text{Li}/\text{sec}$

200

$10^{12} \text{ } ^8\text{Li}/\text{sec}$

2000

12 m from KamLAND center

$10^{13} \text{ } ^8\text{Li}/\text{sec}$

20000



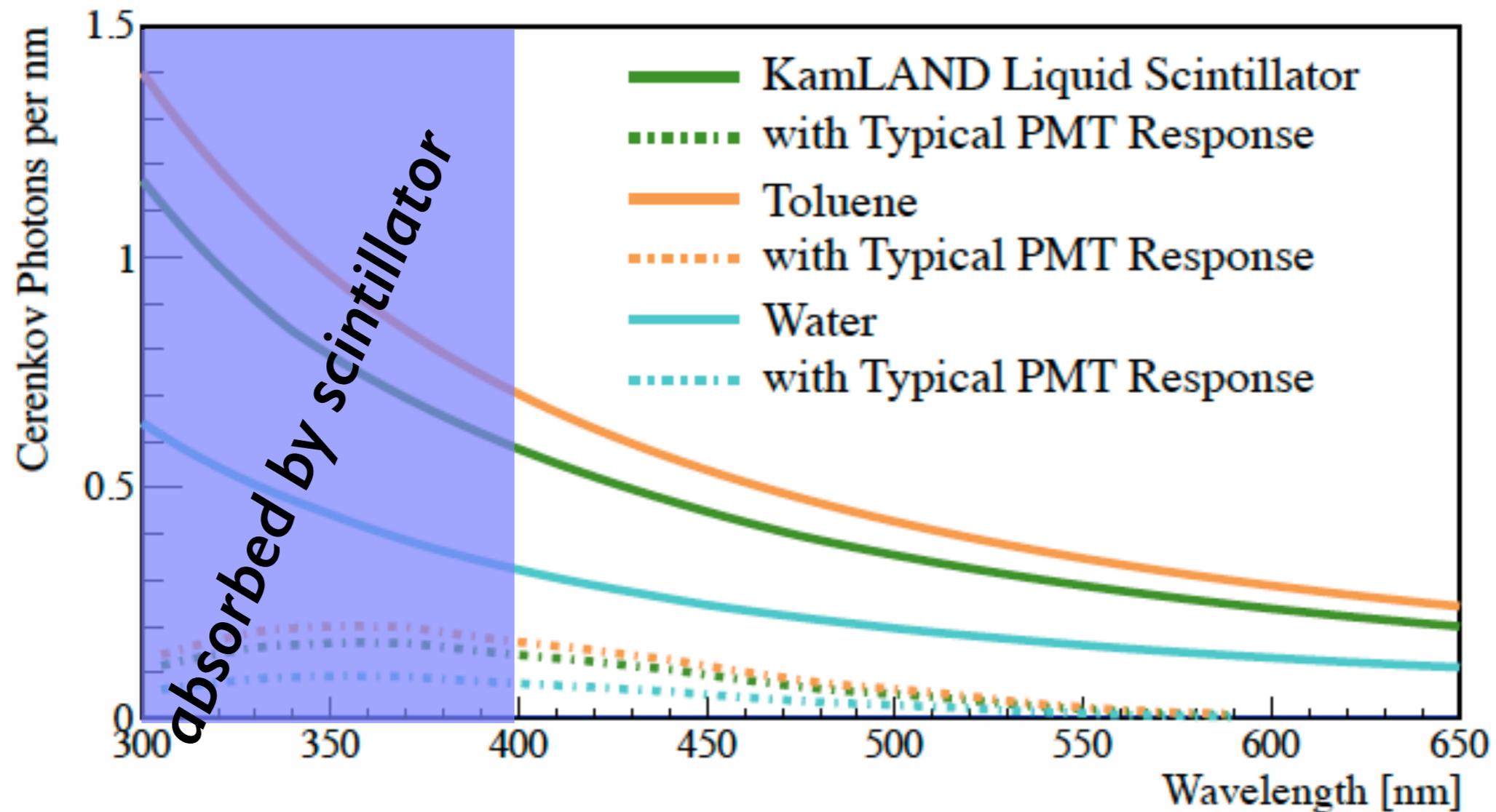
# NuDot: A Prototype Directional Liquid Scintillator



THE UNIVERSITY OF  
CHICAGO

# How does it work?

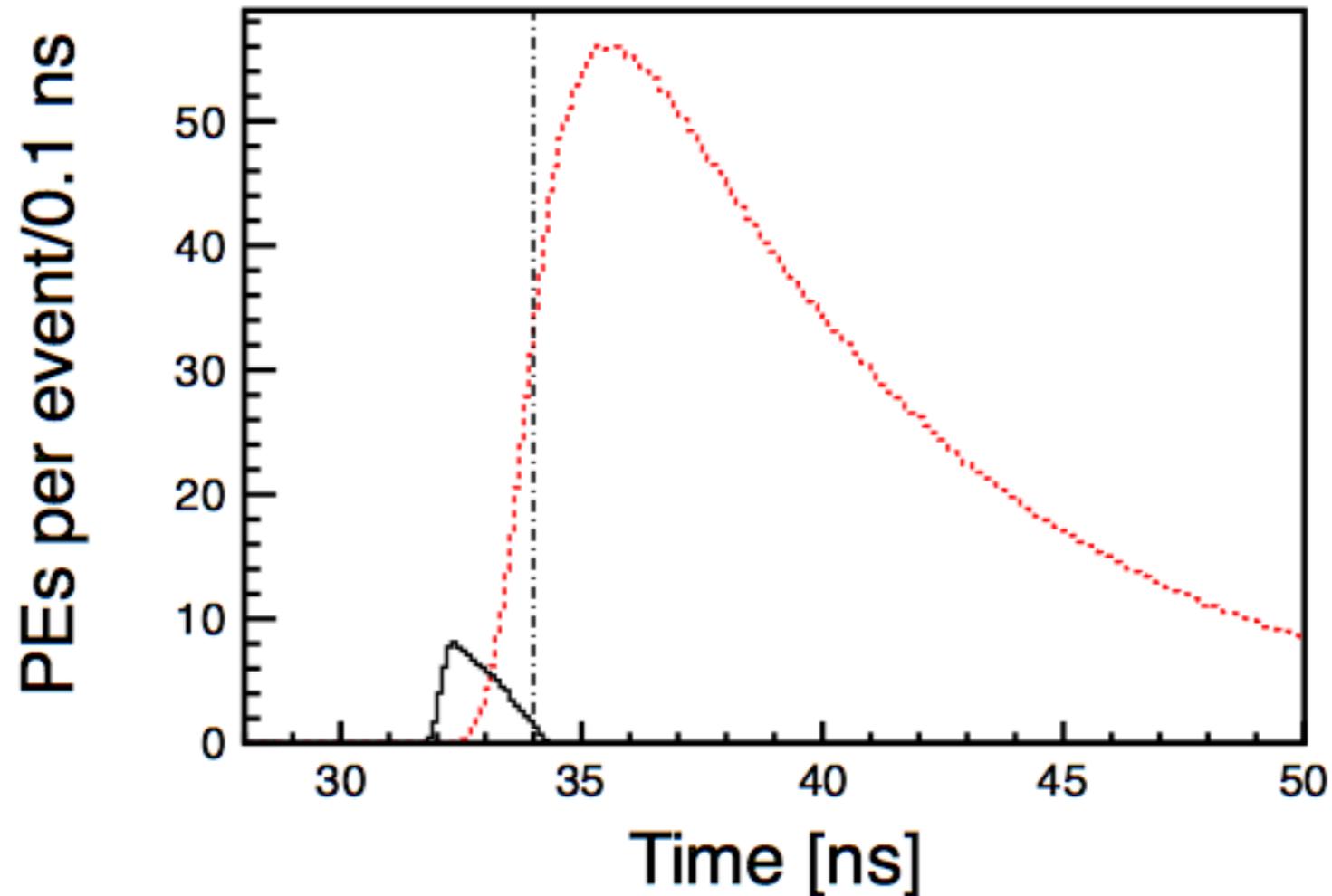
Number of Cherenkov Photons for a 1 MeV  $e^-$



Retains directional information!

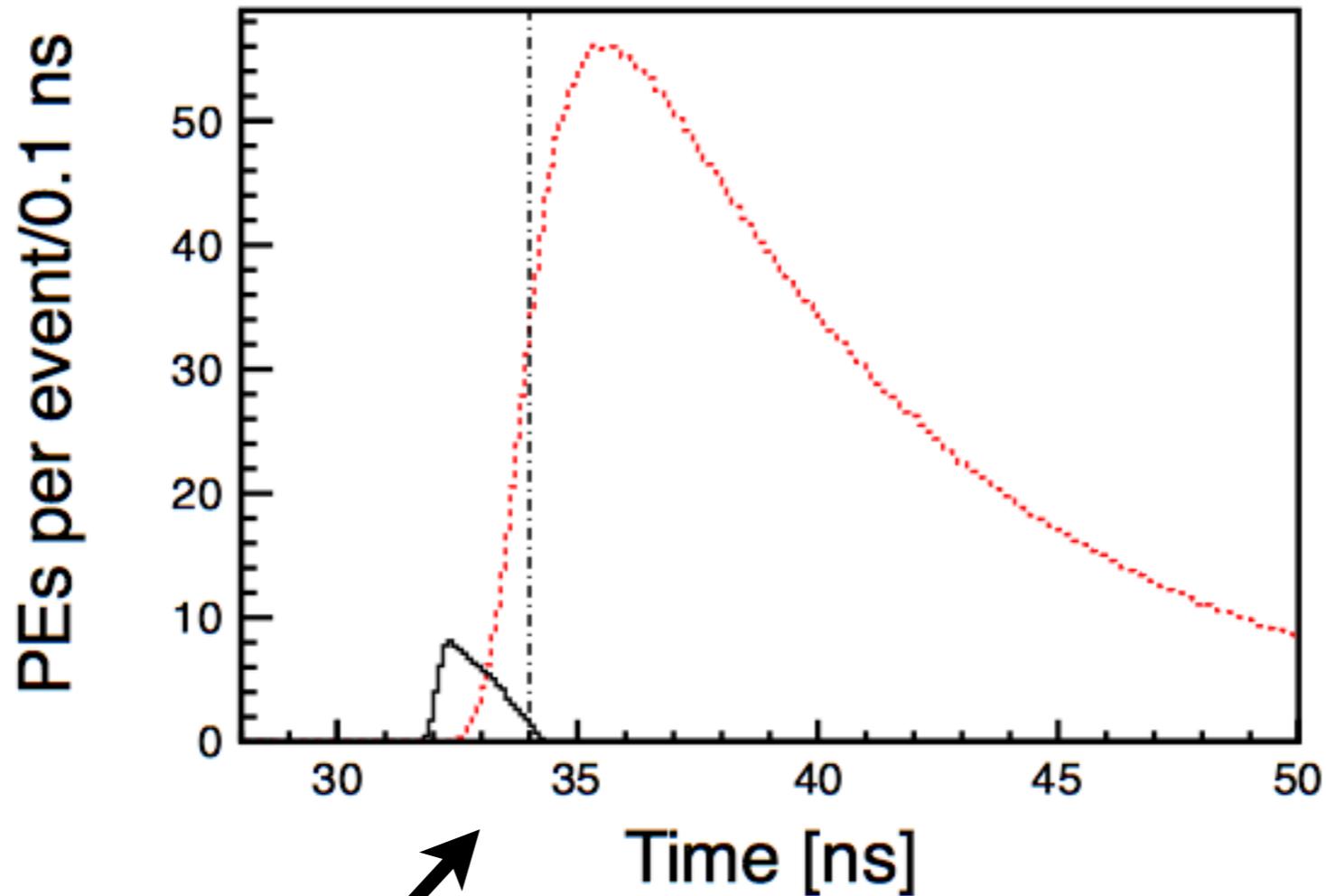
**Longer wavelengths travel faster in scintillator and scintillation processes have inherent time constants.**

So if you have good enough timing....



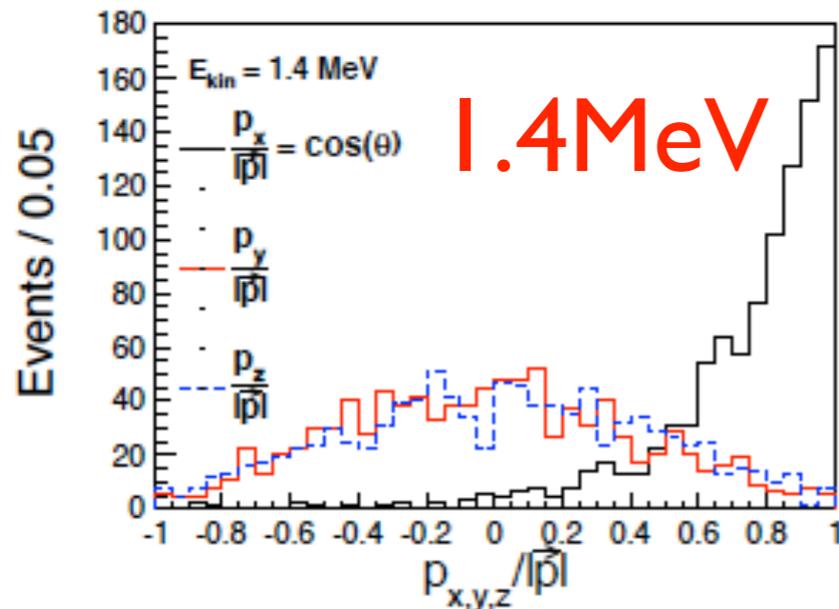
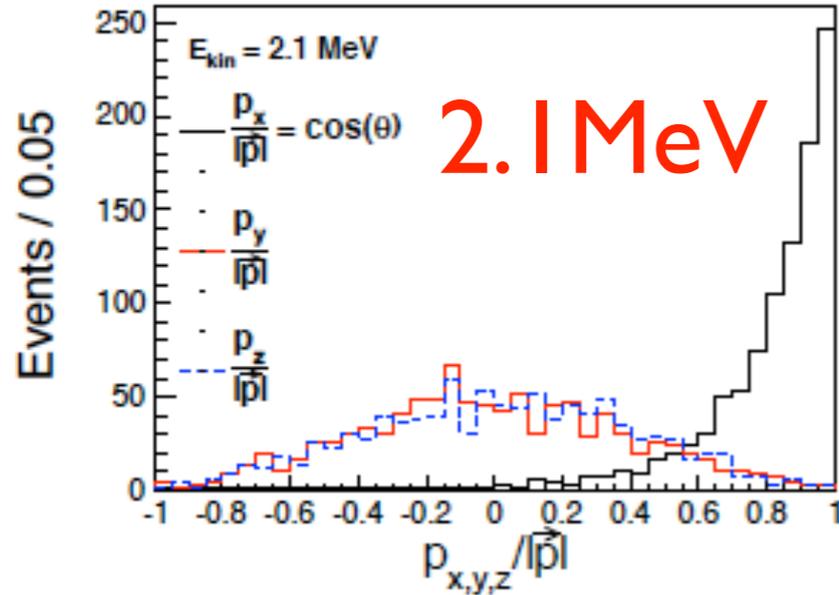
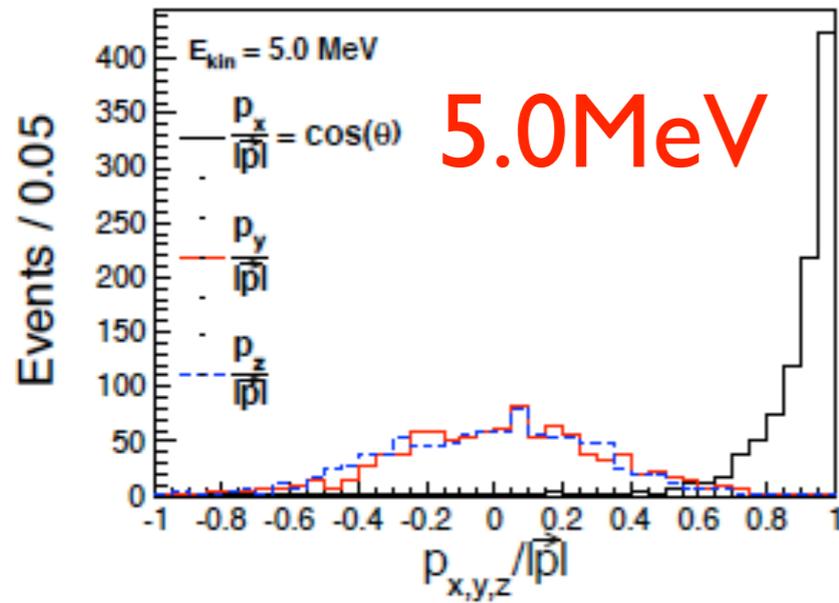
you should be able to separate the scarce Cherenkov from the abundant scintillation light.

This is a simulation of a 6.5m spherical detector with 0.1 ns timing resolution.



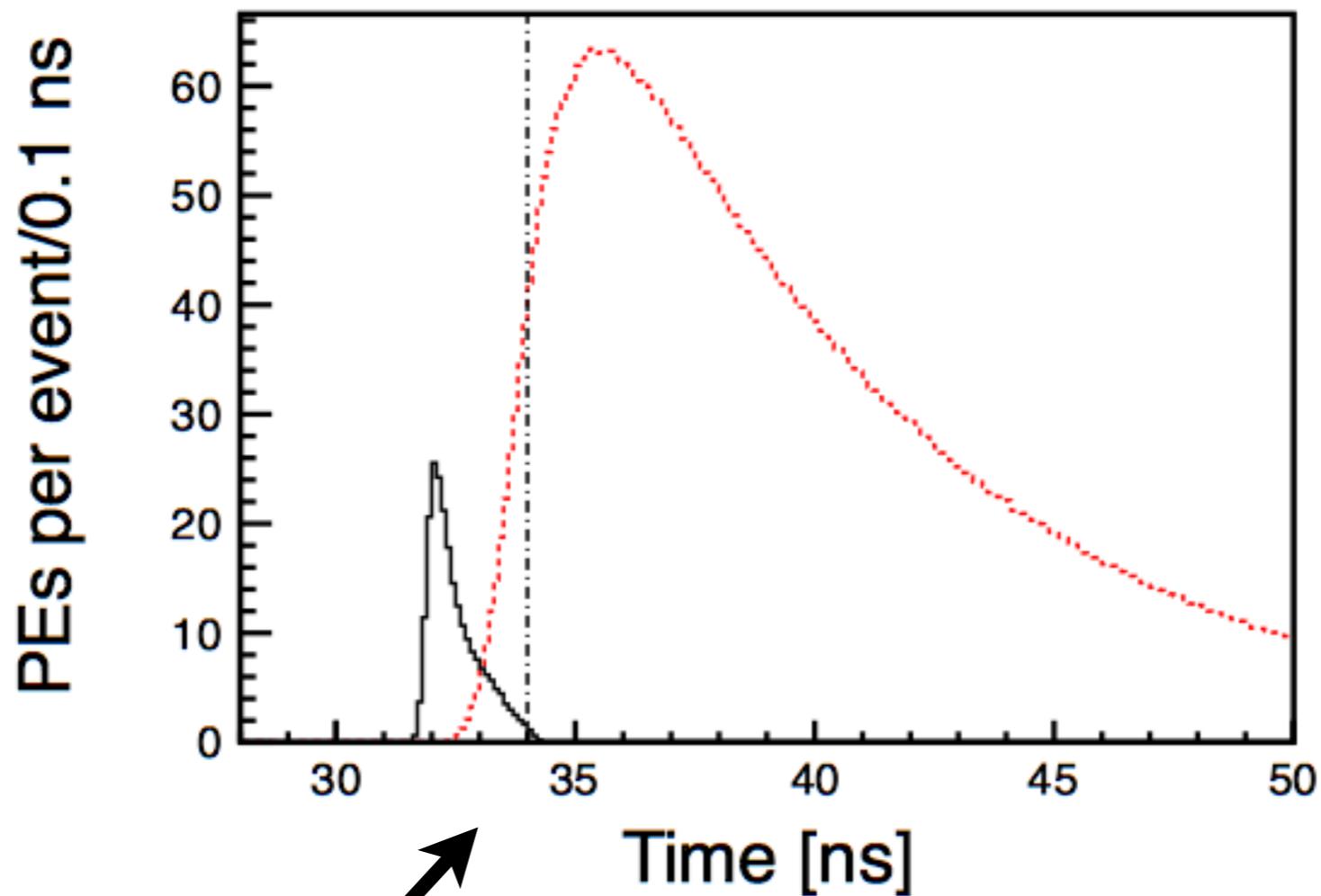
$R_{c/s} = 0.63$

*The LAPPD could provide the needed time resolution.*



**With a basic algorithm, we can reconstruct the direction of single electrons!**

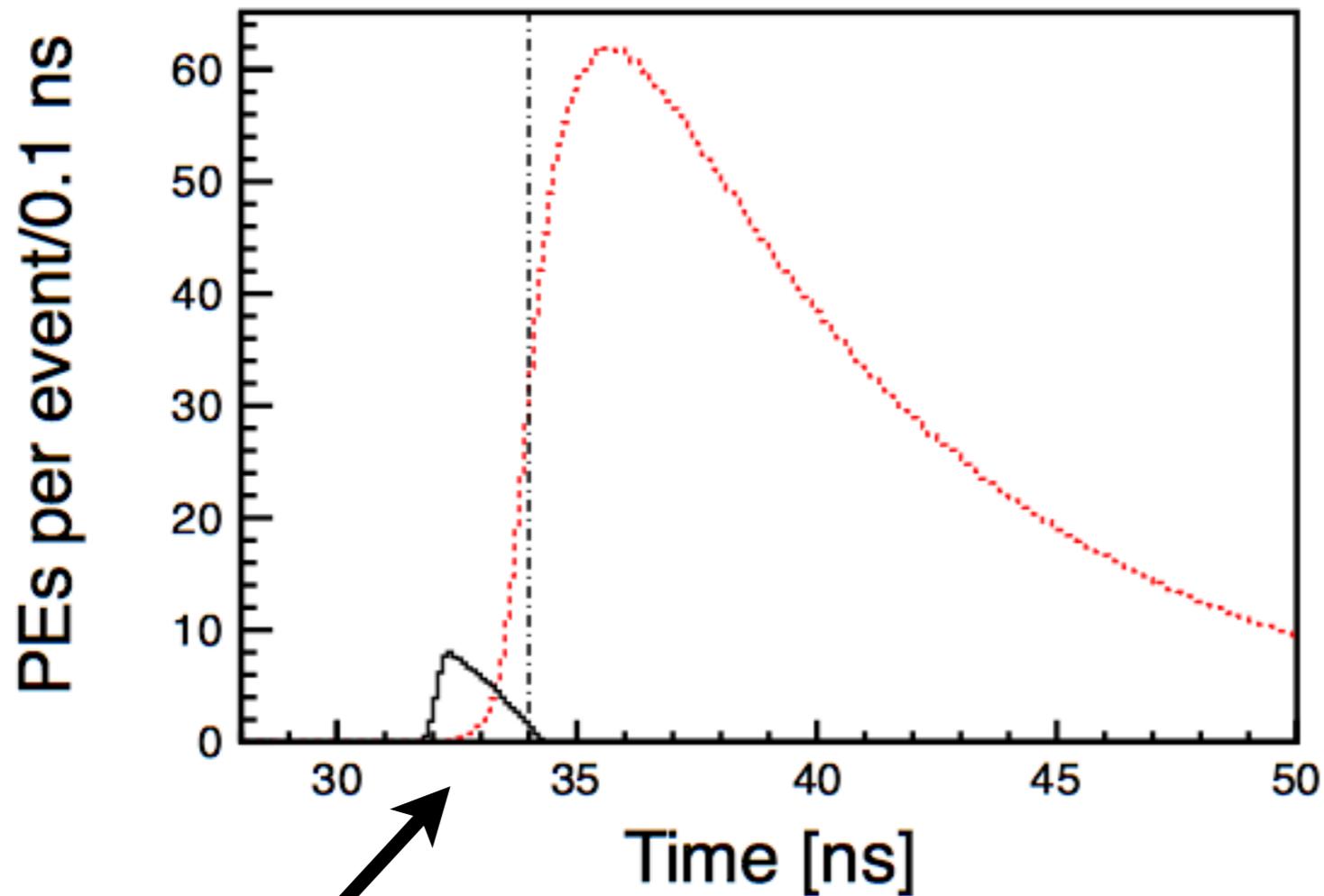
This effect could be enhanced with a large red-sensitive PMT..



$R_{c/s} = 1.01$

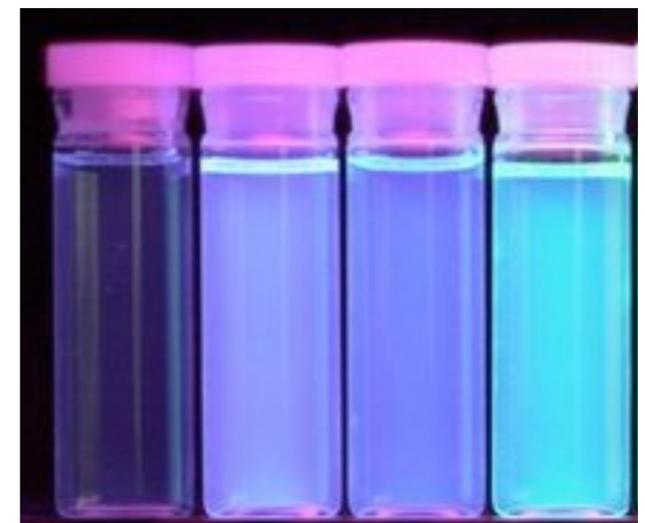
*This exists in 1 cm diameter..*

This effect could also be enhanced with a narrowed scintillation emission spectrum.

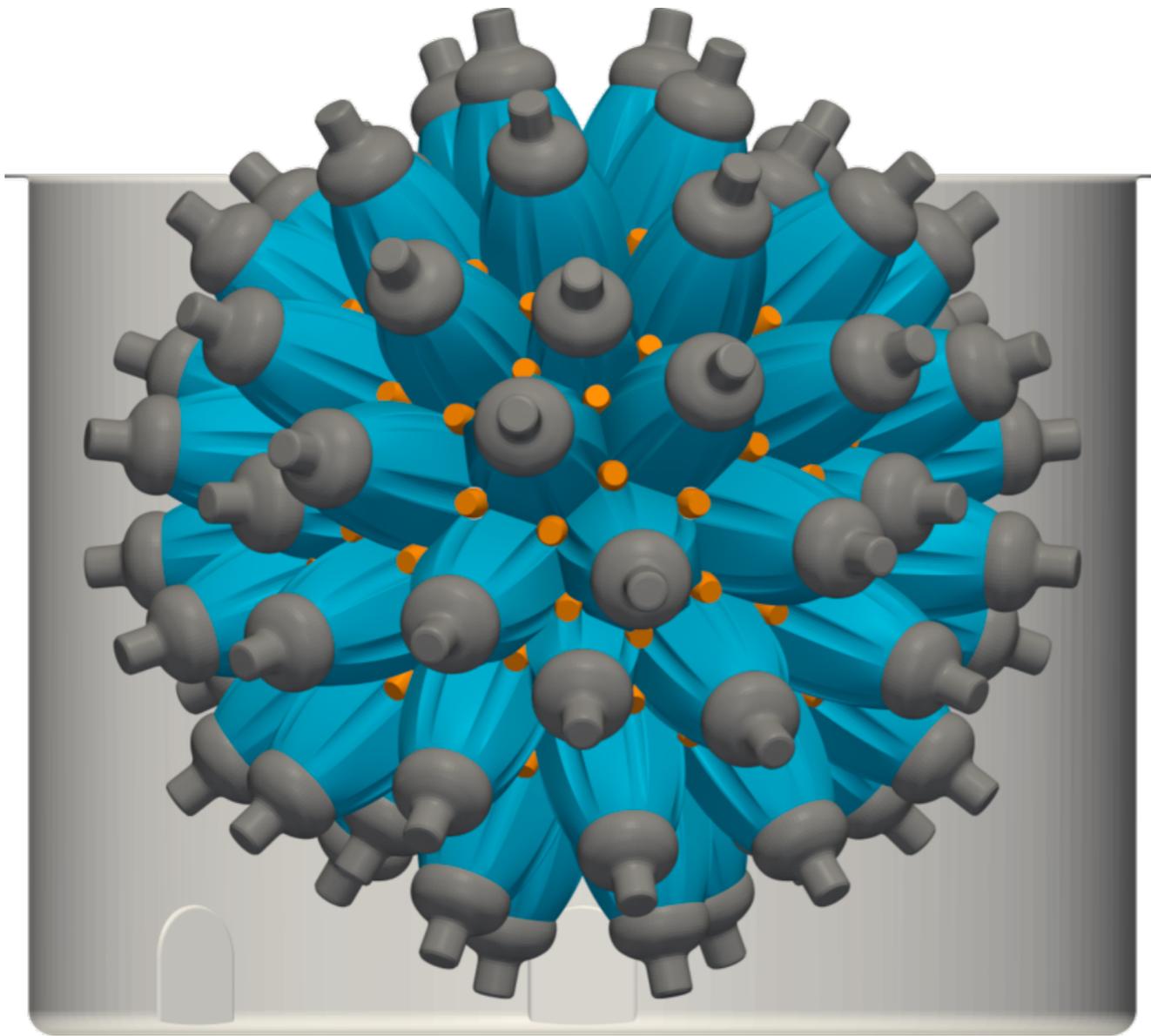


*This could be done with nanoparticles called quantum dots.*

$R_{c/s} = 0.86$



# NuDot Under Construction Summer 2015

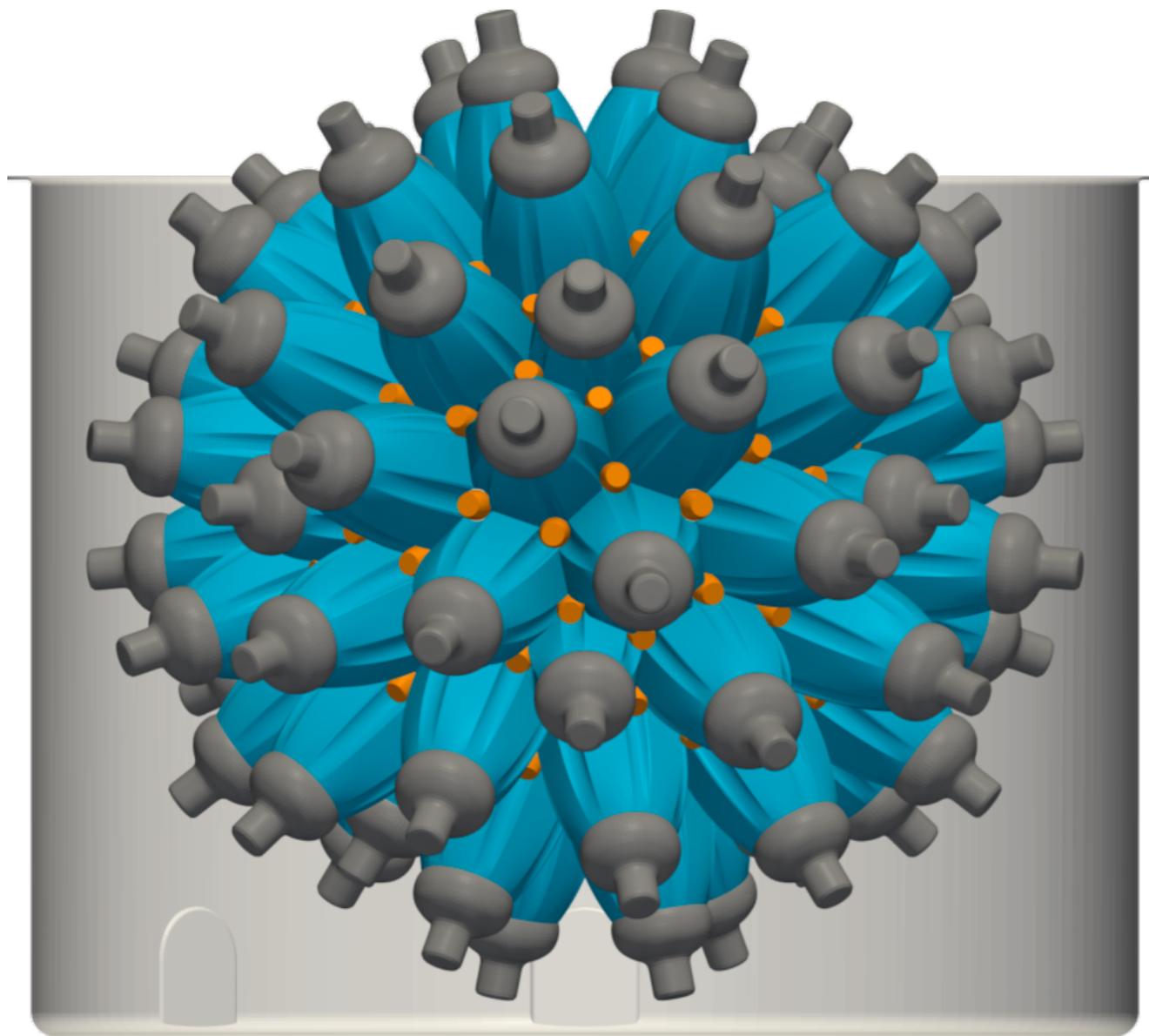


- 140 2-inch fast PMTs for timing (orange).
- 72 ~10-inch PMTs mounted on Winston Cones (blue) for resolution.



**2170 mm**

# NuDot Schedule



**2170 mm**

**2015 - Commissioning above ground with a tagged Compton source.**

**2016 - Possible photodetector upgrade.**

**2017 - Move underground for  $2\nu\text{BB}$  measurement.**

**Quantum-Dot-Doped scintillator development ongoing.**



**NuDot is focussed on the search for double-beta decay but a directional scintillator would find applications in many other areas from neutrino-electron scattering experiments to geoneutrino searches.**

**We are working closely with the KamLAND-Zen and THEIA Collaborations and thank them for their collaboration.**